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Fiber Bragg Gratings
Theory, Fabrication, and Applications

Marcelo M. Werneck, Regina C. Allil, and Fábio V. B. de Nazaré

Tutorial Texts in Optical Engineering
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Introduction to the Series

Since its inception in 1989, the Tutorial Texts (TT) series has grown to cover many diverse fields of science and engineering. The initial idea for the series was to make material presented in SPIE short courses available to those who could not attend and to provide a reference text for those who could. Thus, many of the texts in this series are generated by augmenting course notes with descriptive text that further illuminates the subject. In this way, the TT becomes an excellent stand-alone reference that finds a much wider audience than only short course attendees.

Tutorial Texts have grown in popularity and in the scope of material covered since 1989. They no longer necessarily stem from short courses; rather, they are often generated independently by experts in the field. They are popular because they provide a ready reference to those wishing to learn about emerging technologies or the latest information within their field. The topics within the series have grown from the initial areas of geometrical optics, optical detectors, and image processing to include the emerging fields of nanotechnology, biomedical optics, fiber optics, and laser technologies. Authors contributing to the TT series are instructed to provide introductory material so that those new to the field may use the book as a starting point to get a basic grasp of the material. It is hoped that some readers may develop sufficient interest to take a short course by the author or pursue further research in more advanced books to delve deeper into the subject.

The books in this series are distinguished from other technical monographs and textbooks in the way in which the material is presented. In keeping with the tutorial nature of the series, there is an emphasis on the use of graphical and illustrative material to better elucidate basic and advanced concepts. There is also heavy use of tabular reference data and numerous examples to further explain the concepts presented. The publishing time for the books is kept to a minimum so that the books will be as timely and up-to-date as possible. Furthermore, these introductory books are competitively priced compared to more traditional books on the same subject.

When a proposal for a text is received, each proposal is evaluated to determine the relevance of the proposed topic. This initial reviewing process has been very helpful to authors in identifying, early in the writing process, the need for additional material or other changes in approach that would serve to strengthen the text. Once a manuscript is completed, it is peer reviewed to ensure that chapters communicate accurately the essential ingredients of the science and technologies under discussion.

It is my goal to maintain the style and quality of books in the series and to further expand the topic areas to include new emerging fields as they become of interest to our reading audience.

James A. Harrington
Rutgers University
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Foreword

The confluence of two significant events—on one hand, the discovery of photosensitivity in glass optical fibers in 1978 by Ken Hill; and the other, the side inscription of gratings into fibers by laser holographic means by Meltz and co-workers in 1989—has led the way to over thirty years of strong interest, continuous research, and a myriad of developments and innovations in the field of optical fiber-Bragg-grating technology.

Fiber Bragg gratings (FBGs) are one of the most useful, versatile, practical, and attractive passive devices in the fields of optical fiber communications and fiber optic sensors. This prominence is the result of their simplicity of operation coupled with their attractive and unique features, such as all-fiber construction, self-wavelength-value referencing, absolute encoding, capability for multi-point cascading, and batch fabrication, to name a few. A multitude of FBG devices are commonly used in different optical communication applications, such as dispersion compensators, gain lockers, spectral filters, wavelength references, and several more. Similarly, there is a broad variety of different sensors based on FBG elements that allow for the measurement of temperature, pressure, strain, acceleration, moisture, bio-chemical agents, and many other parameters in diverse civil and defense applications that range from aerospace structural health monitoring, to oil- and gas-well sensing, to miniature intra-aortic pressure and temperature probes.

Furthermore, despite over three decades of R&D activity and a mature FBG industry, there still remains a vast group of engineers, scientists, students, and new end-users engaged in the research and utilization of FBGs in novel applications. This process can be exemplified by the new femtosecond-IR-laser writing techniques; the advent of regenerated gratings for high-temperature operation; and the inscription of FBGs in novel, specialty optical fibers—from polymer to microstructural versions. Such technology advancements demand that students and researchers remain informed and up-to-date in the field, which makes the availability of a suitable textbook that can provide to the reader (in a simple and succinct fashion) the technology’s basics, its applications, and recent innovations all the more necessary and valuable both to the expert as well as to the neophyte in the field.
This new book fills such a knowledge gap. As the name implies, it is a practical manual that provides the reader with basic but concrete and useful information on the fundamentals and key practical aspects of the operating principles, design, fabrication, and simple use of FBGs in general.

The book authors are well known in the fields of fiber optics and optical fiber sensors, and they have over 70 years of combined experience. Their experience in academia and applied research affords them a unique insight as well as the ability to strike a nice balance—between theory and practical guidelines—and they have done an excellent job in covering the material in an easy-to-understand way without sacrificing technical soundness. In addition, the material covered is extensive and reviews many of the potential areas of interest to any reader, from the operating basics of FBGs, its fabrication methods, measurement techniques, and their utilization as light-wave-tailoring devices and sensors.

In my opinion, this tutorial appeals to a broad and diverse audience, especially to nontechnical individuals and those becoming familiar with FBGs for the first time. It should be a “must have” reference book for anyone working in the field of fiber Bragg gratings.

Alexis Méndez
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Preface

The development of optical fibers has revolutionized not only telecommunications but also the way monitoring and sensing is conducted, particularly in remote or harsh environments. In this context, the discovery of photosensitivity in optical fibers led to the establishment of fiber Bragg gratings (FBGs), optical filters that have been widely employed in telecom and as measurement elements.

This Tutorial Text discusses these optical devices directly, focusing on the practical aspects and applications. It addresses the fundamental aspects of FBG operation to quickly introduce the subject to students, engineers, and laboratory technicians. Due to their inherent advantages in instrumentation, sensing, and automation systems, FBGs play an important role not only for industry professionals but also for academics. Thus, this book is primarily intended for scientists, professors, researchers, students, photonics technicians, and engineers involved in optical-fiber projects.

The chapters follow a logical sequence: after a discussion of the primary concepts, practical aspects regarding the development of a FBG laboratory and how these components are manufactured and used in practical applications are presented. The following chapters outline the operation of Bragg gratings and, for instance, discuss how measurement information can be retrieved (interrogation techniques), calibration methods, and how to prepare and deploy the devices in real monitoring conditions. The final chapters present several successful, real-world applications of the technology.

*Fiber Bragg Gratings: Theory, Fabrication, and Applications* delivers essential information concerning FBGs to professionals and researchers with an approach based on rules of thumb and practical aspects, enabling quick access to the main principles and techniques, and allowing readers to set up their own laboratory or application. It provides detailed information about how to operate and use these novel sensors, particularly with respect to the required infrastructure, daily operation, and possible applications. Dense physical aspects and the associated refined mathematical models are not thoroughly presented because this information can be found in other publications.

Many of the applications in this book reflect our own experience in courses, M.S. dissertations, D.S. theses, and projects at the Laboratório de
Instrumentação e Fotônica (LIF) of the Universidade Federal do Rio de Janeiro. Therefore, we acknowledge our former and present students who made it possible to accomplish all of work that went into this book. We also acknowledge the contributions of the following D.S. students: Marceli Nunes Gonçalves and Leandro Alves Garção for writing Chapter 12, and Bruno Cerqueira Rente Ribeiro for writing Chapter 16.

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